Studies for the Synclite Scale

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1. Introduction

The Synclite instrument is used to measure the transverse profiles and positions of the proton and pbar beams in the Tevatron. Synchrotron light emitted at the edge of a magnet is picked off by a mirror and via a telescope and image intensifier is imaged by a CID camera[1]. The reported beam positions and sizes contain a scale. Since the beam profiles are imaged onto 640x480 pixels, the scale used is given as a number in mm/pixel. The original scale used was taken from Run 1 and was obtained by optical imaging. To check the scale we did two beam studies where we used closed orbit 3-bumps to move the beams a known (calculated) distance and checked to see what the Synclite system reported[2]. Though the proton scale agreed, the beam study scale for pbars gave a scale that is a factor of about 1.8 different from that used in Run 1. Checks of the optical scale were done at two different times and these are reported in this memo.

2. The Optical Scale

The optical system used to image the synchrotron light consists of just a single lens and some mirrors. A schematic is shown in Figure 1. The magnification (size of image/size of object) is given by $M = S_i / S_O$ where the image should be located at the focal point of the lens. The focal length f is given by $1/f = 1/S_i + 1/S_O$.

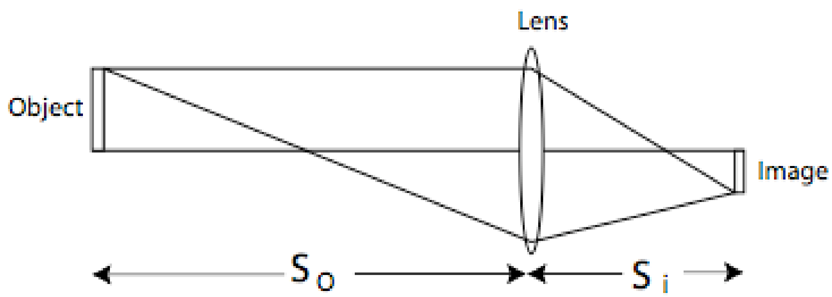


Figure 1. Schematic for Synclite imaging system.

The image is captured in a camera with a known mm/pixel scale $= P_C$, then for an image size of N pixels, the size of the object is just $(N \cdot P_C)/M$. The effective mm/pixel scale is therefore P_C/M. As part of the check of the optical scale, we measured the distances S_i and S_O for both the proton and pbar systems and we also took out the lens in the pbar system and measured its focal length. The measurements of the distances of the lens to object and lens to image are give in Figure 2 and Figure 3.

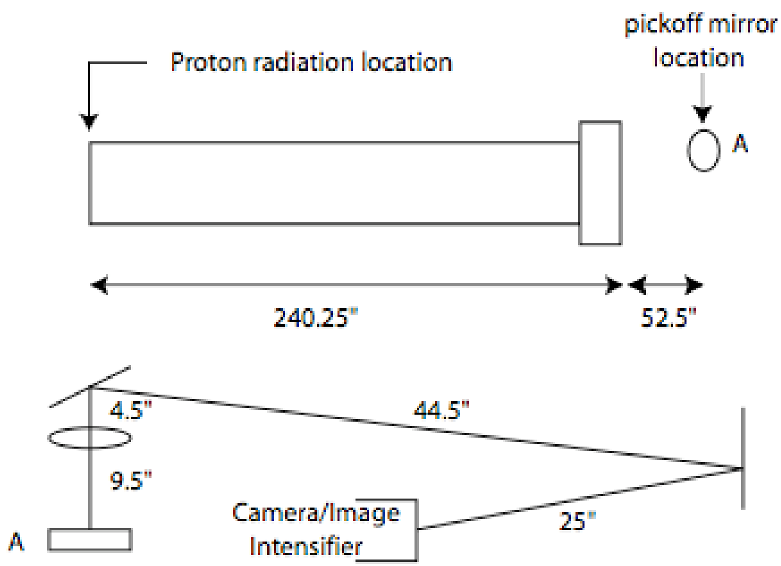


Figure 2 Schematic of the proton light path from radiation point to the image intensifier and camera, showing the measurements of the light path distances.

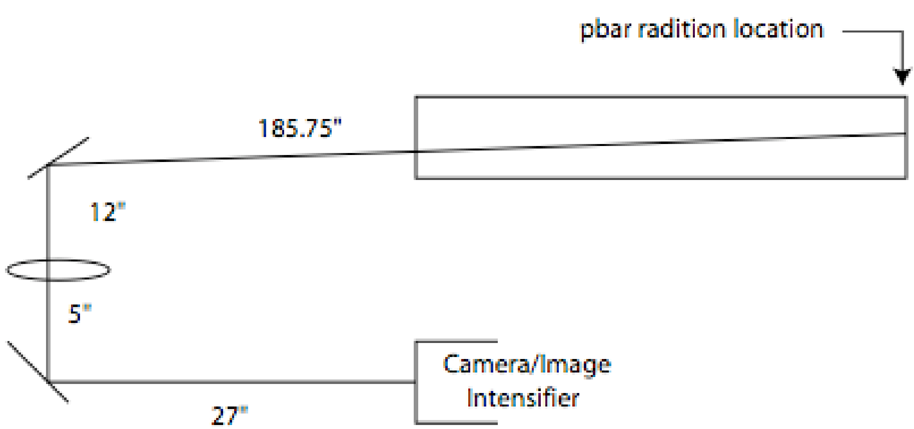


Figure 3 Schematic of the pbar light path from radiation point to the image intensifier and camera, showing the measurements of the light path distances.

The CIDTEC cameras used for both the proton and pbar systems have the model number CID3710D, which contains a sensor with 776H×512V pixel elements. The actual active pixel elements though is specified as 755H×484V and the pixel size is specified as 12.0μm×13.7μm. This image is sent and captured by a video frame grabber that maps this image onto a standard VGA size of 640×480 pixels. This means that the effective pixel size of the video image (used in the LabVIEW analysis) is 14.2μm×13.8μm assuming it is the active sensor pixels that are captured, (otherwise the size would be 14.6μm×14.6μm.) I will thus take the image pixel size to be 14 microns per pixel ($= P_C$) for both horizontal and vertical.

The measured parameters determining the optical scale is given in Table 1 and compared to the original (Run 1) Synclite scale and the scale obtained in the closed orbit 3-bump beam studies[3].

Table 1 Parameters determining the mm/pixel scale in the proton and pbar systems.

Item	Proton	Pbar
S_i (inches)	74.00	32.00
S_O (inches)	302.25	197.75
Measured focal length (inches)	-	30±2
Magnification (M)	0.245	0.162
Optical scale (mm/pixel)	0.057	0.087
Scale used in Run 1 (mm/pixel)	0.058	0.083
Beam study scale (mm/pixel)	0.052	0.149

Given that the calculated sizes of the beam bumps used in the beam study is probably only known to within about 10% errors the proton mm/pixel optical scale agrees with that obtained in the beam study. However the pbar mm/pixel optical scale is different from that obtained in the beam study by a factor of 1.7 which is not understood. Note that the beam study uses movements of the beam so only image centroids from Synclite are used. Another check of the Synclite scale is to compare the measured emittances to those from the Flying Wires. Here the comparison is more complicated as the lattice numbers have to used to compare the two measurements and resolution sizes of the Synclite system has to be accounted for. The comparison with the Flying Wires will be the subject of a future memo.

The distances S_i and S_O for the pbar system were also measured by Andreas Jansson and Stephen Pordes to be 30.75 inches and 198.5 inches respectively[4].

3. Trying to Check the Pbar Scale

Besides checking the magnification M by measuring the distances S_i and S_O, we also checked the camera/video image pixel size. This was done by using a mask placed in front of the image intensifier. The mask completely covers the photocathode of the image intensifier except for a small hole that is placed off-center by a distance R =1.71mm. The UV calibration lamp is used to illuminate the mask resulting in an image at the hole location. By rotating the mask and measuring the different positions of the images in Synclite, we can use the Synclite system to determine R and hence the mm/pixel scale (P_C) of the camera/video imaging system.

Two masks were made, one with a hole of diameter 0.016 inches and the other with a larger hole of diameter 0.032 inches. Both masks were measured at SiDet on a precision microscope table[5]. The distance between the centers of the mask and the center of the hole, R, was measured to be 1.719mm and 1.710mm for the small hole and larger hole masks respectively. The error on this measurement is about 0.005mm due to the imperfect roundness of the two holes.

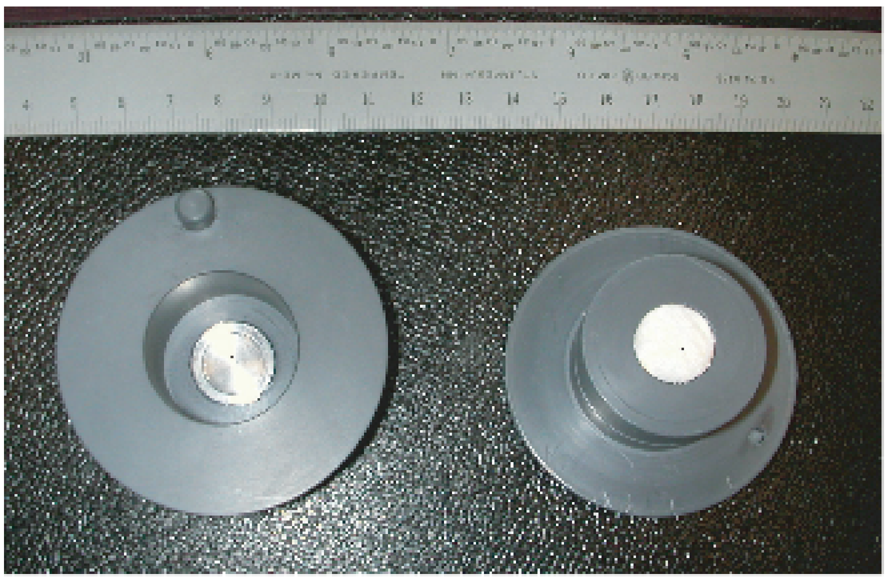
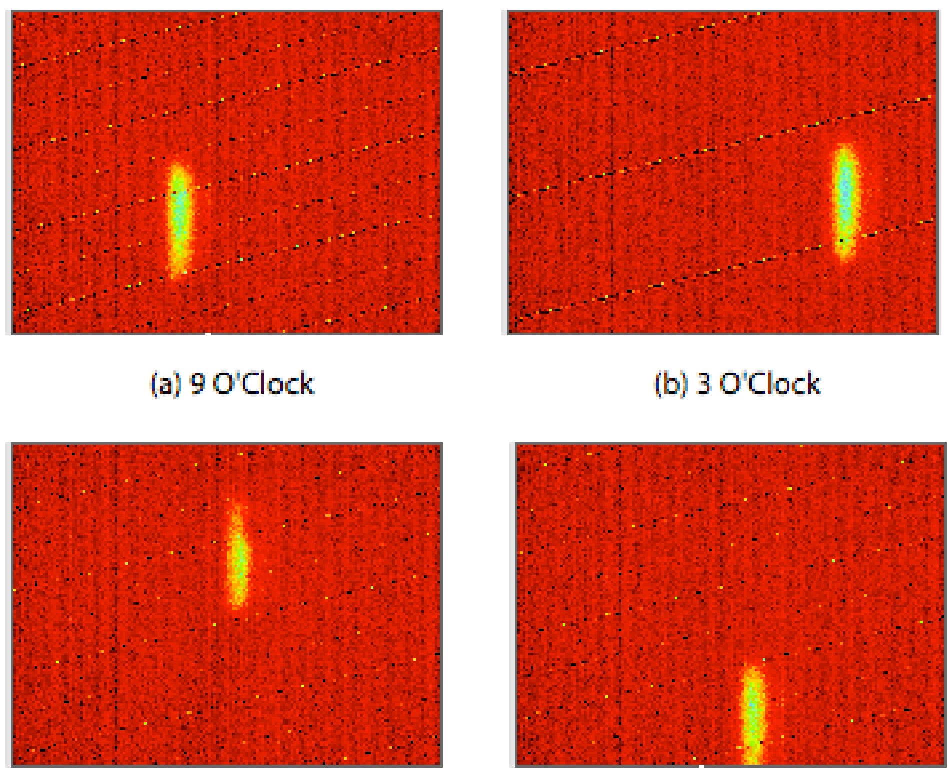


Figure 4 Photograph of the two masks. The photocathode of the image intensifier is recessed in a fixture and the top part of the "top hat" inserts into this space to place the hole as close to the photocathode as possible.

The UV lamp is a black light about 6 inches in length and about 1/2 inch in width[1]. One problem with the procedure was that the photocathode is several mm back from the glass window of the image intensifier so the hole that should produce the image is not in close contact with the photocathode. This means that the hole in the mask acts as a pin-hole camera and creates an image of the UV lamp that is long and thin. Since the Synclite program tries to fit a Gaussian to the projection, the long image could not be fit.

The images as seen in Synclite for the pbar system are given in Figure 5 for different positions of the hole in the mask. Since only the horizontal fit succeeded, only the horizontal positions are used. These are given in Table 2. From the estimated positions of the hole, we can estimate that $2R$ to be 21.2/0.083=255 pixels. (Synclite reported the distance as 21.2mm using the old scale of 0.083 mm/pixel, done on Nov. 19 2002.) Given the value of $R = 1.72$ mm, the camera/video scale (P_C) is determined to be 13.5 μm/pixel. This agrees well with the 14 μm/pixel given in the specifications of the camera/video system.



(a) 9 O'Clock (b) 3 O'Clock

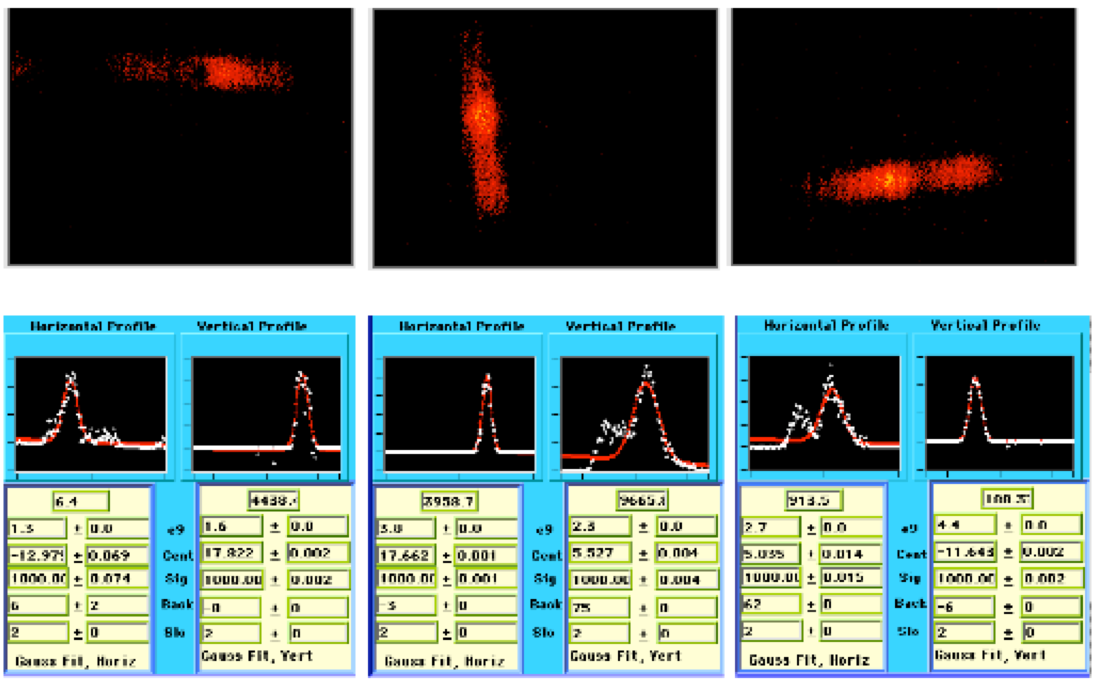
(c) 6 O'Clock (d) 12 O'Clock

Figure 5. 2-D images from the Synclite pbar system for different positions of the hole in the mask. Only the horizontal projections gave a good fit and good horizontal positions.

Table 2 Fit positions in the pbar system from the horizontal projection. The reported numbers are in "mm" using the old pbar scale of 0.083 mm/pixel.

Hole Position	Horizontal Fit Position (mm)
9 O'Clock	6.030
12 O'Clock	-2.701
3 O'Clock	-15.213
6 O'Clock	-1.359
7.5 O'Clock	2.094

The uncertainties associated with having only the horizontal projection fits and the uncertainties in the hole/mask positions can be estimated by comparing the horizontal positions of the 6 and 12 O'clock positions. This gives an uncertainty of 16 pixels in 255 pixels, or 6.3%. Thus the camera/video system scale is determined to be 13.5±0.9 μm/pixel, compared to the expected 14 μm/pixel. As a further check this calibration was repeated on Feb. 6 2003. In this second calibration the light from the UV lamp was further masked off to try to get an image for which both the vertical and horizontal projections could be fit. These images for different positions of the mask and the fits of the projections are given in Figure 6. Unfortunately the 3 O'clock position suffered from a double image so only data for 3 positions are given in Table 3. These 3 image positions define a circle with a radius R of 18/0.149=121 pixels, this is illustrated in Figure 7. This second study thus gives a camera/video scale of 14.1 μm/pixel, exactly as expected.



(a) 6 O'clock (b) 9 O'clock (c) 12 O'clock

Figure 6 2-D images and fits of projections from Synclite for the second mask calibration for different positions of the hole/mask. The 3 (x,y) positions define a circle.

Table 3 Fitted Gaussian centers of the horizontal and vertical projections for the second mask study, for different hole locations.

Hole Location	Fitted Center Horizontal (mm)	Fitted Center Vertical (mm)
6 O'clock	-12.973	17.808
9 O'clock	17.734	5.702
12 O'clock	4.937	-11.579

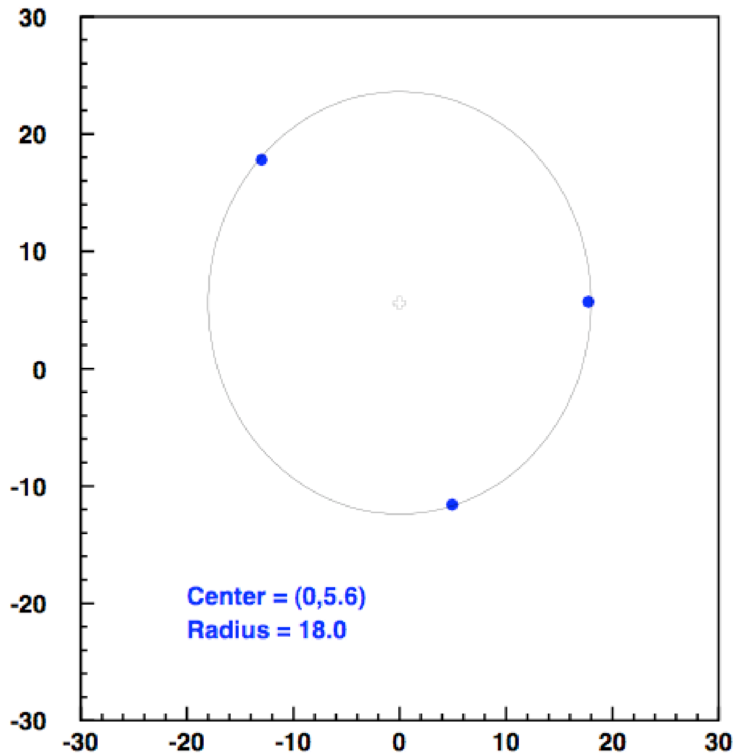


Figure 7 Fitted x and y locations for the 3 mask positions that define a circle allowing the determination of the radius which is the quantity R described in the test.

4. Conclusions

Checks were made of the optical magnification and camera/video image mm/pixel scales. These point to scales for Synclite of 0.057 mm/pixel and 0.087 mm/pixel for the proton and pbar systems respectively which is consistent with the 0.058 and 0.083 mm/pixel original scales used in Run 1. There is therefore still an inconsistency in the pbar scale as obtained in closed orbit 3-bump beam studies which give a scale of 0.149 mm.pixel.

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[1] See http://home.fnal.gov/~cheung/synclite/ for a description of the Synclite system.

[2] H.W.K.Cheung, "Bumping the orbit to calibrate the SyncLite 2 scale", SyncLite/2002/001, Beams-doc-215. H.W.K.Cheung, "Second beam orbit study to calibrate the Synclite scale", SyncLite/2003/001, Beams-doc-459.

[3] Alan Hahn remembers that the lens used in the pbar system has a focal length of 75cm (29.5") and the lens in the proton system has a focal length of 150cm (59.1").

[4] A. Jansson and S. Pordes, "Synclight Geometry", Beams-doc-417.

[5] Many thanks to Greg Sellberg for doing the measurements.